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GAMMA RAY IMAGING SYSTEM

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a gamma ray imaging system, and, more particularly relates to a gamma ray imaging system for generating and displaying an image signal which is representative of an image of a gamma ray emitting source.

2. Description of the Prior Art

Gamma ray emitting sources are most commonly found in nuclear power plants and in nuclear contaminate sites. During nuclear power plant operation, routine monitoring of potential highly radioactive areas must be performed. Environmental restoration and waste management of radiation contaminated sites also require detecting and locating contaminants to assure restoration of the environment to the safe level. Additionally, in order to perform repairs and maintenance within nuclear power plants, the area to be worked in must be scanned by Health Physics personnel to determine an amount of exposure the radiation workers will encounter while performing their job. Worker radiation exposure is closely monitored via personally worn dosimetry and radiation workers who have reached government specified radiation exposure limits are prevented from further exposure and can no longer perform their jobs. Thus, it is extremely beneficial and the goal of all nuclear power plant operators to minimize personal radiation exposure in highly radioactive areas so that radiation exposure limits are not reached.

The Health Physics personnel responsible for scanning a potentially highly radioactive area must wear protective clothing and a respirator to protect them

against airborne radiation. The scanning is performed using a well known device called a Geiger-Mueller counter. Geiger-Mueller counters are relatively small and are carried by the worker performing the scanning process. In some instances, the Geiger-Mueller counter is attached to a pole so that the worker can maintain a safe distance from radioactive equipment when scanning. The worker manually scans the entire area to determine "hot spots" or areas of high radiation.

Upon completion of the scanning process, the worker creates a map of the radiation hazards which have been identified by the scanning process using the Geiger-Mueller counter. The worker must remember the location of the "hot spots" and subsequently map them to the best of his ability. Based upon the results of the scanning process, radiation workers performing repairs and maintenance are instructed how long they can remain in the area and what equipment should be avoided due to high levels of radiation being emitted. Furthermore, the scanning process is time consuming because the sweep rate, i.e., the rate at which the Geiger-Mueller counter handpiece is moved over a radioactive source, is relatively slow. In some instances, the worker must get close to the gamma ray emitting source to obtain proper readings since typical Geiger-Mueller counters are not very sensitive.

The two most important factors in limiting radiation exposure are time of exposure and distance from the source of radiation. Presently available scanning techniques using a Geiger-Mueller counter are inefficient in minimizing time of radiation exposure and maximizing distance from the source of radiation. Additionally, the scanning process using a Geiger-Mueller counter provides crude "hot spot" location.

Accordingly, there is a need for a portable, reliable, gamma ray imaging system which can automatically map out "hot spots" in an area to be monitored. Furthermore, it would be advantageous to have a device which can be permanently mounted in an area to provide a map of the radiation environment in an area with no radiation exposure to human beings.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the invention to provide an automatic gamma ray imaging system which can display an image representative of an image of a gamma ray emitting source.

It is another object of the present invention to provide a reliable device which can be permanently mounted in an area to provide a display of an image representative of an image of a gamma ray emitting source.

It is yet another object of the present invention to provide a device for mapping radiation "hot spots" while minimizing human exposure to radiation hazards.

It is still a further object of the present invention to provide a device for providing real-time surveillance of radiation hazardous areas.

It is yet another object of the present invention to provide a portable device for monitoring and locating potential hazardous radioactive sources and material in the nuclear industry and to safeguard the safety and health of personnel working in the industry and the populous residing in surrounding areas.

It is still a further object of the present

invention to provide a gamma ray imaging system for use at security check points to detect the smuggling of nuclear materials.

It is yet a further object of the present invention to provide a gamma ray imaging system which is affordable, rugged, reliable and user-friendly.

It is still a further object of the present invention to provide an imaging system for imaging both gamma and x-rays.

It is yet a further object of the present invention to provide an imaging system to perform X-ray tomography.

In accordance with one form of the present invention, a gamma ray imaging system for providing an image of a gamma ray emitting source includes a coded mask, a position sensitive detector, an array of charge coupled devices and a signal processor. In an alternative embodiment, an array of semiconductor photodiodes may be used in place of the array of charge coupled devices. The array of photodiodes function in a similar manner to the array of charge coupled devices.

The coded mask is adapted to receive gamma rays emitted by a source. The coded mask generates a coded shadow in response the gamma rays received by the mask. The position sensitive detector is situated with respect to the coded mask to allow the coded shadow generated by the mask to impinge on the detector. The position sensitive detector generates a coded optical signal in response to the coded shadow impinging on the position sensitive detector. The array of charge coupled devices are responsive to the coded optical signal and generates a coded electrical signal from the optical signal. The signal processor is responsive to the coded electrical

signal and decodes the coded electrical signal and generates an image signal therefrom. The image signal is representative of an image of a gamma ray emitting source.

The gamma ray imaging system may also include a means responsive to the image signal for displaying a representative image of the gamma ray emitting source. The image signal responsive means may be a cathode ray tube similar to a television monitor. Furthermore, the gamma ray imaging system may include a means for transferring the coded optical signal from the position sensitive detector to the array of charge coupled devices. The transferring means may be either an array of fiber optic tapers or relay optics.

The gamma ray imaging system of the present invention may still further include an image intensifier. The image intensifier is interposed between the position sensitive detector and the array of charge coupled devices. The image intensifier amplifies and intensifies the coded optical signal to provide increased sensitivity to the system. The image intensifier may be in the form of an image intensifier tube.

The coded mask of the gamma ray imaging system includes areas of gamma ray transparency and opacity. The coded mask may be in the form of ~~or~~ a uniformly redundant array or any other type of coded array.

The position sensitive detector of the gamma ray imaging system may be a glass scintillator or a glass fiber scintillator. The glass fiber scintillator includes a plurality of glass fibers and the glass fibers preferably include an external mural absorber coating on the glass fibers to minimize cross-talk between the fibers. In alternative embodiments, the position

sensitive detector may be formed from a plastic fiber scintillator or a crystal scintillator.

The gamma ray imaging system of the present invention is optimally designed to provide a maximum field of view of the area being monitored. To maximize the field of view, the coded mask includes a cross-sectional area which is approximately two times the cross-sectional area of the position sensitive detector. The field of view preferably ranges from about 1 degree to about 45 degrees.

The imaging system structure described above can also be used to provide an image of an x-ray emitting source. Accordingly, the imaging system may be useful in the field of nuclear medicine, and more specifically in the field of x-ray tomography or nuclear radiography.

The present invention also discloses a method of generating a representative image of a gamma ray emitting source. The method includes the steps of providing a gamma ray imaging device including a coded mask, a position sensitive detector, an array of charge coupled devices and a signal processor, each of which functions as previously described, situating the gamma ray imaging device so that a gamma ray emitting source is within a field of view of the device, and displaying an image signal generated by the signal processor, the displayed image signal being representative of an image of the gamma ray emitting source.

The method may further include creating a visual overlay of an area in the field of view of the device and displaying the image signal in conjunction with the visual overlay of the area. In this manner, the gamma ray image is superimposed on a pictorial overlay of the area and "hot spots" can be easily determined.

An alternative embodiment of the gamma ray imaging system includes a coded mask, a position sensitive detector and a signal processor. The coded mask receives gamma rays emitted by a source and generates a coded shadow. The position sensitive detector is situated with respect to the coded mask to allow the coded shadow to impinge thereon. The position sensitive detector includes an array of semiconductor gamma ray detectors which generate a coded electrical signal in response to the coded shadow impinging thereon. The signal processor is responsive to the coded electrical signal and decodes the coded electrical signal to generate an image signal which is representative of an image of the gamma ray emitting source.

A preferred form of the gamma ray imaging system, as well as other embodiments, objects, features and advantages of this invention will be apparent from the following detailed description of illustrative embodiments thereof, which is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side perspective view of a portable portion of a gamma ray imaging system formed in accordance with the present invention.

Figure 2 is a functional block diagram of a gamma ray imaging system formed in accordance with the present invention.

Figure 3 is a side elevational view illustrating the arrangement of the coded mask with respect to the position sensitive detector.

Figure 4 is a functional representation of a coded mask, coded shadow and image of a gamma ray source recovered by signal processing and decoding in accordance with the present invention.

Figure 5 illustrates a coded mask having a 17 x 19 uniformly redundant array formed in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A gamma ray imaging system formed in accordance with the present invention offers a unique system to enhance health and safety and reduce potential hazards associated with gamma ray emitting sources, and, particularly in nuclear power plant and nuclear contaminated site restoration operations. Presently available techniques for monitoring and mapping potential radiation hazardous locations are inefficient, time-consuming and subject workers to unnecessary radiation exposure. Conventional scanning techniques involve the use of a Geiger-Mueller counter to manually scan a location to determine "hot spots" or sources emitting large doses of gamma radiation. The gamma ray imaging system of the present invention is orders of magnitude more efficient than the conventional method of manual scanning with a Geiger-Mueller counter for locating hazardous radiation and gamma ray emitting sources.

The gamma ray imaging system provides a device which can be permanently installed for continuous monitoring or which can be deployed in a hand-held unit as needed. The gamma ray imaging system alleviates the problems associated with manual scanning by workers and enables a real-time surveillance of "hot spots" or highly radioactive areas. In one application, the gamma ray imaging system may be strategically installed in a

containment chamber of a nuclear power plant to produce a gamma ray image which can be overlaid on a visual image of the area to pinpoint potential radiation hazards. Thus, potential radiation contaminated structures can be identified in real-time and required corrective actions can be undertaken immediately. Additionally, permanently installed gamma ray imaging devices formed in accordance with the present invention may eliminate the need for personnel exposure to radiation hazards to perform routine inspections in potentially hazardous areas.

The gamma ray imaging system formed in accordance with the present invention may be useful in the nuclear power and nuclear material production and processing industries, nuclear waste management, the decommissioning of nuclear reactors, in nuclear powered vessels, in scientific facilities and even in nuclear medical applications such as nuclear radiology. The imaging system of the present invention can also be used at security check points to detect the smuggling of nuclear materials. In effect, the applications for using the gamma ray imaging system of the present invention are rather expensive.

The gamma ray imaging system formed in accordance with the present invention provides a rugged, real-time, imaging system that is affordable, portable and user-friendly for effective monitoring of areas of hazardous radiation, including both X-rays and gamma rays. Such a system is presently not available in the marketplace. Imaging systems for astronomical observation of celestial bodies emitting high energy have been successfully developed by NASA; however, these systems are bulky, expensive, difficult to operate and used exclusively for astronomical observations. They are not suitable as environmental radiation monitors because of their size, cost, operating complexity and weight.

Referring to Figure 1, a gamma ray imaging system formed in accordance with the present invention generally includes a protective case or housing 2 which encloses a coded mask 4, a position sensitive detector and an array of charge coupled devices. In an alternative embodiment, an array of semiconductor photodiodes can be used in place of the array of charged coupled devices; however, the preferred embodiment utilizes an array of charge coupled devices. The housing may include a handle 6 for portability of the device. A cable 8 has one end coupled to the array of charge coupled devices and an opposite end coupled to a remote image processing location.

Figure 2 illustrates a functional block diagram of a gamma ray imaging system formed in accordance with the present invention. The gamma ray imaging system generally includes a coded mask 4, a position sensitive detector 10, an optical train 13, an image intensifier 11, an array of charge coupled devices 12 and a signal processor/decoder 14. The coded mask 4 provides approximately 50 percent transparency to gamma rays emitted by a source and received by the coded mask. The coded mask 4 generates a coded shadow in response to the gamma rays received by the mask. The position sensitive detector 10 is situated with respect to the coded mask 4 to allow the coded shadow generated by the mask to impinge on the position sensitive detector. The position sensitive detector 10 generates a coded optical signal in response to the coded shadow impinging on the detector. The optical train 13 optically couples the position sensitive detector to the array of charge coupled devices 12 which are responsive to the coded optical signal generated by the position sensitive detector and generates a coded electrical signal. The coded electrical signal is received by a signal processor 14 which processes and decodes the coded electrical signal and generates an image signal therefrom. The image

signal is representative of an image of the gamma ray emitting source and may be displayed on a cathode ray tube 16 or the like. The embodiment illustrated in Fig. 2 also includes control electronics for controlling the array of charge coupled devices.

In an alternative embodiment, the position sensitive detector includes an array of semiconductor gamma ray detectors. The array of gamma ray detectors are adapted to receive the coded shadow and generate a coded electrical signal in response to the coded shadow impinging thereon. The array of gamma ray detectors formed in accordance with the present invention includes an integral semiconductor device having the inherent properties of a scintillating material and an array of charge coupled devices to convert the coded shadow to a coded electrical signal.

The coded mask 4 may be a mask based on a uniformly redundant array or any other type of coded array mask. In one particular embodiment of the present invention, the coded mask 4 is based on a uniformly redundant array design. This type of mask offers relatively high transparency (approximately 50 percent) and high signal-to-noise ratio. The coded mask 4 is made from lead or other high density material and may consist of a 2 x 2 mosaic of the basic coded array. The arrangement of the mask 4 relative to the position sensitive detector 10 is shown in Figure 3.

The field of view of the gamma ray imaging system is dependent upon the arrangement of the coded mask 4 relative to the position sensitive detector 10. For example, the largest field of view is achieved by a shortest mask to position sensitive detector separation. A preferred embodiment of the gamma ray imaging system includes a means for adjusting the separation distance

between the coded mask and the position sensitive detector. By adjusting the separation distance, the device may include a zoom feature, for example, of 1.5 times. In order to achieve the zoom feature, the distance separating the coded mask 4 and position sensitive detector 10 is increased by a predetermined amount dependent upon the desired magnification.

As shown in Figure 3, the coded mask 4 includes two cycles of a basic coded array and is approximately twice the size in cross-sectional area of the position sensitive device 10 to maximize the fully coded field of view. As previously mentioned, the fully coded field of view is a function of the mask size and the separation distance between the coded mask 4 and the position sensitive detector 10. The field of view preferably ranges from approximately a few degrees to about 45 degrees.

Since the mask 4 is made from a high density material, it is desirable to limit the size and thickness of the mask due to weight considerations. High opacity required for the opaque portion of the coded mask requires the use of a thick mask. One embodiment of the gamma ray imaging system may include a coded mask having a uniformly redundant array in the form of 17 x 19 basic array configuration in a 2 x 2 mosaic. As an example, the mask may be approximately 6 x 6.7 inches and have a thickness of approximately 2 cm. A mask having these design parameters weighs approximately seven pounds. The described mask has a mask opacity of approximately 0.4 at 1.3 Mev. It is desirable for opacity to be as close to unity as possible.

The coded mask, which consists of an array of opaque and transparent elements is placed between the emitting sources and a position sensitive detector plane. Every

object element emitting gamma rays within the field of view projects a shadow of the aperture on to the detection plane or position sensitive detector.

Figure 4 is a functional representation of a coded mask design and the coded shadow formed on the position sensitive detector. The coded mask forms multiple image shadows on the position sensitive detector. The position sensitive detector generates an optical signal in response to the multiple image shadows, and the coded optical signal is subsequently converted to a coded electrical signal which is decoded to provide a decoded image signal representative of the initial rays received by the coded mask.

As previously described, the mask may include two cycles of the basic coded array and the position sensitive detector is approximately one half the size of the mask. This configuration provides for a uniform sensitivity over the entire fully coded field of view since the overall transparency of the working zone within the fully coded field of view is constant. The detected flux may be mathematically expressed by $P(x,y)=A(x,y)*O(x,y)+B(x,y)$, where $O(x,y)$ is the object distribution, $A(x,y)$ is the aperture transmission function, $B(x,y)$ is a signal independent background noise and * is the convolution operator.

An estimate $O_e(x,y)$ of the object can be obtained by a suitable decoding function $G(x,y)$:

$$O_e(x,y)=G(x,y)*P(x,y).$$

Those of ordinary skill in the art understand that various coding and decoding schemes can be used without departing from the scope of the invention. Such coding and decoding schemes are well known to those of ordinary

skill in the art.

Figure 5 illustrates an example of a basic 17 x 19 uniformly redundant array coding. The coded mask shown consists of a 2 x 2 mosaic of the basic coded array, with one row and one column excluded to avoid intrinsic ambiguities.

A uniform redundant array coding has been developed by Fenimore, et al. and described in U.S. Patent Nos. 4,209,780 and 4,360,797 both of which are entitled "Coded Aperture Imaging With Uniformly Redundant Arrays", the disclosures of which are incorporated herein by reference.

The position sensitive detector of the present invention may be formed from either a crystal scintillator, a plastic fiber scintillator, a glass scintillator, or glass fiber scintillator. In the preferred embodiment, the position sensitive detector is a glass fiber scintillator. A suitable high density glass fiber scintillator for use in the imaging system of the present invention is described in U.S. Patent No. 5,122,671 to Buchanan, et al., entitled "Terbium Activated Silicate Luminescent Classes For Use In Converting X-Ray Radiation Into Visible Radiation", the disclosure of which is incorporated herein by reference.

The high density glass fiber scintillator emits light in the green spectral region centered at 534 nm. The glass scintillator may be in the form of either a solid mass of glass scintillating material or in the form of a plurality of glass fibers. In the preferred embodiment, the glass scintillator includes a plurality of fibers and the glass fibers include an external mural absorber coating to minimize the cross-talk between the fibers. The bundle of glass scintillating fibers form

the position sensitive detector in the gamma ray imaging system of the present invention.

The glass fiber scintillator is less costly and much more rugged than crystal scintillators commonly known and used in the past. The light output of a 12 mm thick glass scintillator is about 0.2 foot-Lambert per Roentgen per second for 1.3 Mev photons. In the preferred embodiment, each glass scintillating fiber is approximately 15μm in fiber diameter and the glass fiber assembly is approximately 2 to 3 inches in diameter. Typical ranges of suitable thickness of the glass fiber scintillator include from about 1.5mm to about 12mm.

The advantages of using the glass fiber scintillator as the position sensitive detector in a gamma ray imaging system are improved signal-to-noise ratio, spatial resolution and dynamic range. More specifically, improved signal-to-noise ratio is achieved to the extent that at high energy, the glass scintillators have shown signal-to-noise ratio improvements approaching a factor of two when compared to gadolinium oxysulfide phosphor screens. Additionally, glass scintillators have improved X-ray attenuation which leads to greater utilization of X-ray photons. With respect to spatial resolution, the glass fiber scintillators exhibit a spatial resolution of 25 line pairs/mm (lp/mm) or better at low X-ray energy. By comparison, a high resolution phosphor screen will display 12-14 lp/mm under similar circumstances. The greater signal capability and reduced light scatter within a position sensitive detector formed from a glass fiber scintillator are both factors which lead to a wide dynamic range capability for the detector. System tests with high performance charge coupled device cameras have exhibited a dynamic range of 3000 or more. This also translates to excellent contrast sensitivity for X-ray inspection applications.

In the preferred embodiment shown in Fig. 2, the gamma ray imaging system includes an optical train 13 or a means for transferring the coded optical signal to the array of charge coupled devices. Also shown in Fig. 2, the preferred embodiment includes an image intensifier 11 which is interposed between the position sensitive 10 detector and the array of charge coupled devices 12. More specifically, the position sensitive detector 10 has the side opposite the coded mask coupled to the coded optical signal transfer means 13. An opposite end of the transfer means is coupled to an image intensifier 11 which amplifies and intensifies the coded optical signal. The amplified coded optical signal is input into the array of charge coupled devices 12 which generate a coded electrical signal in response to the coded optical signal.

The optical train 13 or transfer means for the coded optical signal may be either an array of optical fiber tapers or relay optics. Optical fiber tapers are often used to interface or match two optical apertures of differing size, such as the position sensitive detector 10 and the image intensifier 11 or array of charge coupled devices 12. Optical fiber tapers are generally tapered fiber optics having one end with a larger cross-sectional area than the opposite end of the optical fiber. The alternative configuration of the gamma ray imaging system uses relay optics to image the output surface of the glass fiber scintillator to the image intensifier or array of charge coupled devices 12. Both the fiber optic tapers and relay optics are special order commercially available products. For example, suitable fiber optic tapers include special order fiber optics manufactured by Schott Fiber Optics, Inc.

As previously mentioned, the image intensifier 11 amplifies and intensifies the coded optical signal. The

array of charge coupled devices 12 are responsive to the amplified coded optical signal and generate a coded analog electrical signal in response to the coded optical signal. The image intensifier 11 can be any number of commercially available products such as an image intensifier tube manufactured by Hamamatsu Photonics K.K. having model number V33347U. Alternatively, the image intensifier function may be accomplished by the array of semiconductor photodiodes such as those manufactured by Hamamatsu Photonics K.K. having model number S2461.

In the gamma ray imaging system, the array of charge coupled devices 12 convert the amplified coded, optical signal into a coded multiplexed analog electrical signal. The coded analog electrical signal may be processed internally by a signal processor/decoder or at a remote location as shown in Fig. 1. Accordingly, a hand-held device including at least the coded mask, the position sensitive detector 10 and the array of charge coupled devices 12 may be housed within a portable protective case 2. A cable 8 having one end coupled to the array of charge coupled devices 12 and an opposite end coupled to a remote image processor completes the gamma ray imaging system. The coded analog electrical signal is conveyed via the cable 8 to the signal processor which digitizes, formats and decodes the coded analog electrical signal and generates an image signal which is representative of an image of a gamma ray emitting source.

As previously mentioned, an alternative embodiment of the present invention includes an array of semiconductor photodiodes which are responsive to the coded optical signal. The array of semiconductor photodiodes generates a coded electrical signal in response to the coded optical signal. Additionally, the array of photodiodes perform the function of the image intensifier to amplify the optical signal prior to

converting the optical signal to an electrical signal. Accordingly, the imaging system operates in a similar manner to that previously described.

The gamma ray imaging system minimum detectable dosage or sensitivity is a function of the glass fiber scintillator, the image intensifier, the array of charge coupled devices and the mask design. Since the numerical aperture of the glass fiber scintillator is less than the commonly used optical fibers comprising the optical fiber tapers, light emitted by the scintillator is coupled to the optical fiber tapers without any reflection. If a 1.5 inch diameter image intensifier tube was used, an optical fiber taper with approximately 2x magnification can be used to match the glass fiber scintillator to the image intensifier tube. Assuming an 80 percent optical transmission, transmission through a 2x magnification optical fiber taper will be reduced to about 50 percent because of excessive magnification and propagation losses in the fiber optic tapers. Therefore, assuming a typical current response of 0.04 A/W for the input phosphor, a gain of 10,000, and a P20 output phosphor for an image intensifier tube, the responsivity of the gamma ray imaging system detector comprising a 3-inch glass fiber scintillator, a 2x fiber optic taper and a 1.5 inch image intensifier tube is about 1 x 10^{-3}w-sec/cm^{2}-roentgen.

In the preferred embodiment using an array of charged coupled devices, the noise equivalent irradiance of the array of charge coupled devices may be reduced by cooling the array with a two-stage thermoelectrical cooler. Typically, operating arrays of charged coupled devices operating at 16 frames per second have a noise equivalent irradiance of about 2.5 x 10^{-9}w-cm^{-2}. By cooling the array of charge coupled devices, the noise equivalent irradiance is reduced to about 6.5 x 10^{-12}w-cm^{-2}. If an 80 percent coupling efficiency

between the image intensifier tube and the array of charge coupled devices is achieved, the sensitivity of the gamma ray imaging system for 1.3 Mev photons is approximately 3 μroentgen/sec or 10mr/hr when operating at 16 frames per second. The sensitivity reduces to about 5nr/sec or 10μr when operating at 1 frame per second. The array of charge coupled devices are commercially available from a number of manufacturers. A suitable array of charge coupled devices for use in the present invention are manufactured by Eastman Kodak Company and have Model Number KAI-0370.

Additionally, the sensitivity of the gamma ray imaging system may be further improved by several means including usage of multistage image intensifier tubes or high gain Silicon avalanche photo diode arrays, or even multiplexing with several optical fiber tapers and image intensifier tubes which will improve the sensitivity by one or two orders of magnitudes. Application of a scanning linear avalanche photo diode array can also provide better sensitivity with an increased frame and integration time.

The signal processor used for decoding the coded electrical signal and generating an image signal is preferably a digital signal processor. The signal processor digitizes, formats and decodes the coded, multiplexed, analog electrical signal generated by the array of charge coupled devices and generates an image signal therefrom. The decoding algorithm preformed by the signal processor is dependent upon the mask configuration. In the preferred embodiment the signal processor is part of a radiation hardened digital signal processor module. The radiation hardened digital signal processor module includes a complete digital signal processor mounted on a Versa module Europa sized (6U) double-sided leaded chip carrier module. The radiation

hardened digital signal processor module performs high speed floating and fixed point arithmetic problems while acting as a system controller. A suitable radiation hardened digital signal processor is based upon the Texas Instruments Hardened Ada Signal Processor (HASP) chip as the core digital signal processor.

The radiation hardened digital signal processor provides 32K x 32 of reprogrammable EEPROM memory, 4K of which is reserved for a boot up routine. RAM totaling 384K x 32 is divided into two sections. The first 128K x 32 is a zero wait state. The remaining 256K x 32 requires one wait state. Memories are accessible via a 32-bit primary bus. Means of communicating between multiple processor modules is provided via a 32-bit wide dual port memory "mailbox" on the expansion bus of each module. Using master/slave protocol, the master has full control of the mailbox. The master is capable of broadcasting a message to one or all of the slaves simultaneously. The slaves only write and read from their own mailboxes and indicate to the master when mail is to be picked up. A wraparound capability is preferably provided for self-test purposes and can be used by the master to monitor outgoing messages. All module input\out signals are buffered in a manner such that a module can be powered off without any adverse effects.

As discussed throughout the detailed description, the gamma ray imaging system formed in accordance with the present invention may be made using a variety of commercially available devices depending upon the system requirements. The gamma ray imaging system can be optimized for the specific use intended, which could encompass a wide range of radiation fields. For example, the ranges may be for imaging small amounts of radiation such as environment and decommissioning residuals or

operational ranges for imaging post accident situations, which may be far greater than the extremes of the operational ranges. Additionally, the gamma ray imaging system of the present invention provides the following advantageous features: (1) portable; (2) a large field of view; (3) a zooming capability without loss of resolution for detailed mapping; (4) high sensitivity and wide dynamic range; (5) real-time operation; and (6) operation and display of images and results at remote locations.

Although the illustrative embodiments of the present invention have been described herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various other changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention.